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Ice Engineering

U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

A New Approach to Cold-Weather Concreting

Since the 1930s, the primary approach to cold-weather construction has been to avoid freezing of the concrete during the curing period. The contractor must ensure that the concrete is delivered warm to the construction site, is placed on thawed surfaces, and is kept warm by insulation or by heated enclosures (Fig. 1).

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) has spent much of the past decade studying alternate approaches to cold-weather concreting and has embarked on two parallel paths to introduce a new cold-weather concreting approach to the construction industry—an approach that allows fresh concrete to develop strength while its internal temperature is below freezing. This is made possible by adding chemicals to fresh concrete to depress its freezing point and to accelerate its hydration rate.

Because using chemicals to protect concrete against freezing is not practiced in the United States, CRREL is working with the Civil Engineering Research Foundation (CERF) to develop an acceptance standard for this new approach. Also, because creating, approving, and accepting these new standards is expected to take a long time, CRREL is also working with several state departments of transportation (DOTs) to develop a cold-weather concreting capability with the help of existing admixtures. The work with the DOTs is expected to bring a working version of this new technology to the transportation community in the very near future while the CERF effort targets the long term.

Current practice

Cold weather places serious constraints on today's concreting operations. As temperatures drop, concrete sets more slowly, takes longer to finish, and gains strength less rapidly. If temperatures dip too low, the risk is that the mix water will freeze, resulting in irreparable damage. To avoid difficulties, the American Concrete

Figure 1. Typically, fresh concrete must be protected from the cold. Here, heat is supplied to the underside of plastic tenting.

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Institute (ACI) recommends a minimum concrete temperature of 7°C (45°F) as it leaves the ready-mix plant and a minimum placement temperature of 5°C (41°F) as it cures. Preferably, the concrete should be kept at 10°C (50°F) or above until it has sufficiently cured to serve its intended purpose. It is not a good idea to heat the concrete too much as higher temperatures increase the likelihood of plastic shrinkage, thermal cracking, and flash set. Typically, concrete should not be produced much hotter than 30°C (86°F).

There are several ways to keep concrete warm during curing. If ambient temperatures stay above freezing, the simplest solution is insulation, as insulation is good for only moderate temperatures. For instance, according to ACI, placing 30 cm (12 in.) of concrete (296 kg/m^3 or 500 lb/yd^3 Type I cement) on a substrate at 2°C (36°F) requires about 6 cm (2.5 in.) of insulation (fibrous glass) to maintain the concrete at 10°C (50°F) for seven days when the outside air temperature is a dead-calm 2°C (36°F).

Richening the mix with more cement or using thicker pours allows the insulation to work down to –3°C (27°F), but it is not recommended that insulation be used at lower temperatures. Lower temperatures usually require artificial heat, and the best way to meet this need is to build a temporary shelter and heat it. Whichever protection method is appropriate, the length of the protection period depends on how quickly heat evolves and how quickly it is lost from the concrete, and on how much strength must be gained by the concrete before the protection is removed.

To avoid damage from early-age freezing, ACI recommends that fresh concrete be maintained at 10°C (50°F) for at least 48 hours. This allows the degree of saturation of newly placed concrete to decrease enough so that a single freezing event will not damage the concrete. However, to be able to support temporary construction loads, the concrete should be protected for at least six days. Higher strengths, of course, require longer protection periods.

When properly applied, these protective measures provide good results, but they can be expensive. Depending on the level of cold-weather protection employed, the extra cost per cubic meter of emplaced concrete can range from approximately 20 percent for insulation blankets to over 100 percent for heated enclosures.* Project costs can more than double during the winter. Anything that can be done to help concrete gain strength faster during cold weather can reduce the duration of cold-weather protection, speed up production and, in effect, reduce the in-place cost of concrete.

There are several ways to shorten the protection time. ACI recommends three: (1) use high-early-strength cement, (2) use an extra sack of cement, or (3) use an accelerating admixture. As the name implies, high-early-strength cement causes concrete to shift more of its strength development to the first three days, but does not cause a net gain in ultimate strength. Using this type of cement adds about 4 percent to the cost of concrete.

Using an extra sack of cement has approximately the same effect on early strength as just discussed for the high-early cement, with the added benefit that the ultimate strength is increased by roughly 7 MPa. One sack of cement adds about 6 percent to the cost of concrete.

Accelerators act very much like high-early-strength cement in that early-age strengths are affected. Nonchloride accelerators add about 8 percent to the cost of concrete.

Though these three methods are considered equivalent in their ability to promote rapid strength gain, none can prevent freezing. Consequently, the most costly part of concreting during the winter—heat—is still required if current practice is followed.

* Estimates based on data from R.S. Means, Building Construction Cost Data, 51st edition, for 15-cm slab on grade.

A new approach

A new approach to winter concreting is to use chemical admixtures that allow concrete to strengthen at subfreezing temperatures. Developing such an admixture has long been a goal of builders in the north but, without acceptance standards to support the use of these admixtures, little progress has occurred in the United States. That is, until the mid-1990s when CRREL, together with two firms from private industry, developed prototype cold-weather admixtures.

Though it was clear at this point that chemicals could substitute for heat, the prototypes were never advanced to the commercial stage mainly because of the lack of industry standards. Things virtually came to a standstill for several years until a study done for the Tennessee Valley Authority showed that low-temperature admixtures could be fashioned directly from commercial off-the-shelf admixtures (Korhonen et al. 1998). This finding eventually led to the two programs being conducted today; both are aimed at introducing cold-weather admixtures into everyday practice. Before we discuss how this technology is being transferred to industry, it's a good idea to first discuss how it works.

Cold-weather admixtures are chemicals that depress the freezing point of water and accelerate the hydration rate of cement at subfreezing temperatures. There are numerous chemicals that act as freezing-point depressants and many that function as accelerators of cement hydration. The challenge has been to find chemicals that work together so that they do not harm the concrete or embedded reinforcing steel in the long run. For example, chemicals containing alkalis or chlorides are not likely candidates because they can lead to aggregate

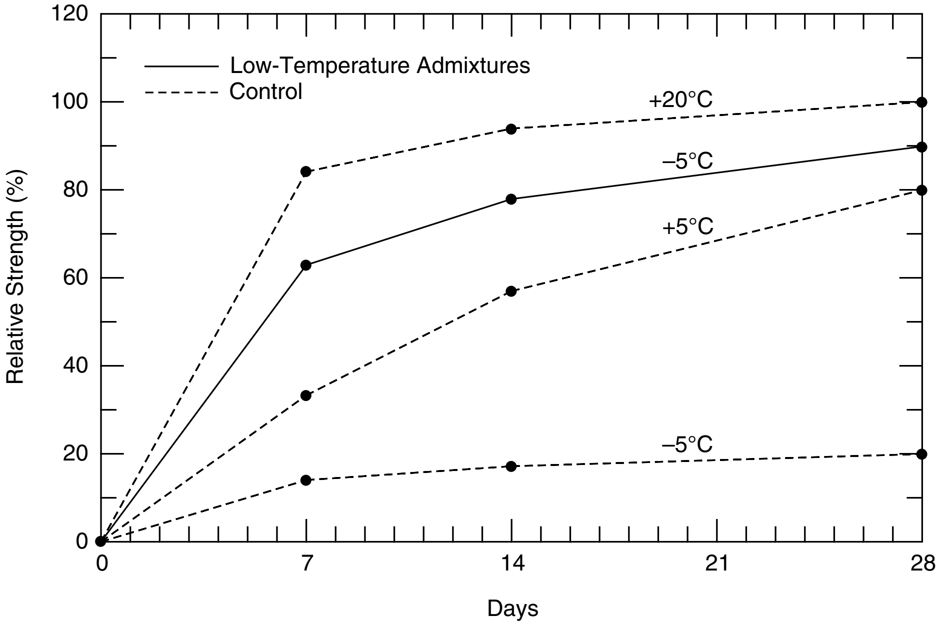

Figure 2. Comparison of control concrete (dotted lines) to concrete made with low-temperature admixtures (solid line) cured at various temperatures.

swelling or to rebar corrosion. Fortunately, there are many chemicals that are benign to concrete and the environment that are available.

Figure 2 compares the performance of one such group of chemicals in concrete cured at –5°C (23°F) to normal concrete cured at various temperatures. The exact chemicals used are not important for this discussion, but it is clear that concrete cured at –5°C (23°F) and made with chemicals of the right kind and in sufficient quantity is able to gain strength as if it was cured at something above 5°C (41°F).

This is significant as a –5°C (23°F) capability translates into an extension of the construction season of two to four months in the United States. In addition to providing extended time to conduct work, cold-weather admixtures allow that work to be done for less cost. Based on past studies, using cold-weather admixtures reduces the cost of winter construction by one-third compared to using heated enclosures (Korhonen and Ryan 2000). This represents considerable savings when it is considered that the U.S. construction industry spent approximately $800,000,000 last winter to thermally protect its concrete (*Civil Engineering* 1991). Therefore, though admixtures may add cost, any increase associated with them is more than offset by savings due to reduced winter protection requirements.

Field tests

This technology has been field-tested several times in the past. In 1994, two prototype admixtures were tested outdoors at CRREL, Hanover, New Hampshire, and at the Corps of Engineers Soo Locks, Sault Ste. Marie, Michigan. At CRREL, a steel-reinforced composting bin 3.7 m wide by 4.6 m long with 1.2-m-high walls, 203 mm thick, all on a 165-mm-thick slab, was cast in February (Fig. 3). In March, the second field test in northern Michigan consisted of replacing several 5.5-m-wide by 6.1-m-long by 150-mm-thick reinforced slabs on grade. The work went smoothly and, in both instances, the concrete is still in service, indistinguishable from control concrete.

In 1997, a low-temperature concrete mixture made with the help of commercial off-the-shelf admixtures was placed in the Sequoyah Nuclear Power Plant belonging to the Tennessee Valley Authority. The concrete was pumped more than 100 m horizontally and 10 m vertically and placed, finished, and cured at –8°C.

In 1999 and 2000, two low-temperature concrete mixtures were developed at CRREL for the City of New York Department of Design and Construction, and Atkins Construction in Bath, Maine. New York wanted the capability to repair its streets and sidewalks later into the fall and earlier in the spring. Atkins Construction wanted to be able to continue concreting operations during the winter to complete the Naval shipyard it was working on. Neither of these two entities has reported using this technology as the last two winters have been mild. However, they are ready should the need arise.

Transferring the technology

As mentioned above, cold-weather admixtures are not commercially available today. Though one may find admixtures marketed for cold weather, close analysis of their performance reveals that they do not allow concrete to gain sufficient strength when its internal temperature is below freezing. They work well only when the air temperature is cold, not the concrete temperature. Thus, to move cold-weather admixtures into practice, two approaches are being tried.

The first approach will develop cold-weather admixtures from those used for various purposes in concrete today. This is being done to avoid the necessity of developing a new acceptance standard. It was decided that a cold-weather admixture could be formulated by combining existing admixtures, which already comply with industry practice. The goal is to not use more of any single admixture than is recommended by its manufacturer but to use sufficient numbers of admixtures so that the concrete can safely resist freezing down to –5°C (23°F).

The admixture-combination must also force the concrete, when it is cold,

Figure 3. Working with cold-weather concrete presents no problems compared to conventional concrete. It is placed, consolidated, and finished in the usual manner. The only protection required is a plastic sheet to cover exposed areas to minimize moisture loss during curing.

to cure as rapidly as control concrete cured at 5°C (41°F). Arbitrarily, the initial setting of cold concrete was tentatively established to be not more than twice that of control concrete cured in standard laboratory conditions. This program, started at CRREL in April 2001, is scheduled to run three years. It is being funded by a consortium of Northern State Departments of Transportation and is being monitored by the Federal Highway Association.

The second approach has the long term in mind, and is being spearheaded by the Civil Engineering Research Foundation (CERF) with the intent to develop a national standard for cold-weather admixtures. During the fall of 2000, CERF gathered a panel of experts from across the United States to develop a draft of what is hoped will eventually become the standard for cold-weather admixtures. It is recognized that developing new standards, getting them approved, and then accepting them into practice takes time—sometimes, years. Thus, this approach will be a natural follow-on to the DOT effort.

Conclusions

Though not quite there yet, the world of winter concreting promises to become a bit friendlier within the next few years and beyond. Expectations are that the protocol for using existing admixtures to make "true" cold-weather admixtures should become available to the DOT community within three years of this writing. This will permit immediate use of this technology to protect concrete down to –5°C (23°F). Following that, a national standard supporting the commercialization of cold-weather admixtures should become available. The timing on this is largely dependent on how quickly this process can move through committee. Once this is done, it is expected that commercial admixtures, dedicated to protecting concrete down to perhaps –10°C (14°F), will enter the market. At that point, cold-weather admixtures will become readily available.

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